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NON-LTE HYDROGEN-LINE FORMATION IN MOVING PROMINENCES

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ABSTRACT

We investigate the behaviour of hydrogen-line brightness variations, depending on the prominence-velocity changes. By solving the non-LTE problem for hydrogen we determine quantitatively the effect of Doppler brightening and/or Doppler dimming (DBE, DDE) in the lines of Lyman and Balmer series. It is demonstrated that in low-density prominence plasmas, DBE in $H\alpha$ *and* $H\beta$ *lines can reach a factor of three for velocities around 160 km/sec, while the* $L\alpha$ *line exhibits typical DDE.* $L\beta$ *brightness variations follow from a combined DBE in the* $H\alpha$ *and DDE in* $L\alpha$ *and* $L\beta$ *itself, providing that all relevant multilevel interlocking processes are taken into account.*

INTRODUCTION

In the present paper we investigate the problem of hydrogen emission emergent from prominence structures moving in the corona. In fact, there exists a vast literature concerning the formation of emission lines in quiescent prominences (see the review by Hirayama, 1985 or Heinzel et al., 1986), but the influence of the prominence macroscopic motions on the amount of the emitted line radiation has not been studied yet in greater detail. Considering the hydrogen spectrum, only Rompolt (1980 a, b) has made some calculations of brightness variations in Balmer lines caused by velocity changes, assuming a two-level atom undergoing radiative transitions. Since there exist several observational indications of, at least, $H\alpha$ brightness variations in different moving structures, which can be explained in terms of the so-called Doppler brightening and/or Doppler dimming effect (DBE, DDE) (see Rompolt, 1967; Hyder and Lites, 1970; Labonte, 1979; Kawaguchi et al., 1984), we address this study to a detailed non-LTE treatment of hydrogen-line formation in moving prominences. We try to assess the prominence brightness variations caused by the macroscopic-velocity changes, keeping other prominence parameters fixed for the moment. As a result, we present here the first quantitative estimates of DBE and DDE in hydrogen lines and briefly discusse the influence of various prominence-plasma parameters on such brightness variations.

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NON-LTE RADIATIVE TRANSFER IN A MOVING PROMINENCE

For the purpose of this rather exploratory work we use a simplified one-dimensional geometry where the prominence is represented by a plane-parallel slab of finite thickness and its motion is simply simulated by determining the velocity-dependent boundary conditions. This schematic approach avoids complicated multidimensional solutions, still keeping the basic non-LTE physics of the problem. For a five-level model atom of hydrogen we solve simultaneously the radiative transfer equations in all Lyman transitions and in the $H\alpha$ line (the radiation field in the remaining transitions is fixed by the external solar radiation), together with the equations of statistical equilibrium and particle and charge conservation equations. The corresponding numerical procedure is the same as that applied by Heinzel et al. (1986) for quiescent prominences. As the basic iteration loop we use a linearization scheme similar to that of Mihalas et al. (1975), supplemented by several equivalent-two-level-atom iterations in order to accelerate the convergence. Hydrostatic equilibrium is treated iteratively. We use all hydrogen opacity sources which are important in low-density prominence plasmas; the hydrogen atomic data were compiled from different sources (inelastic collisional rates are computed according to Mihalas et al., 1975).

As a result, we obtain the overall excitation and ionization balance for hydrogen in the moving prominence, depending on the velocity v, height H above the solar surface and on the basic input parameters M, T, p, v_t. M is the total column mass along the line of sight, T is the kinetic temperature of the plasma, p represents the total gas pressure and v_t characterizes the mean microturbulent velocity. To obtain the correct gas density structure, the prominence is assumed to be composed of helium and hydrogen with the abundance ratio equal to 0.1 (a contribution of helium ionization to the total electron density is negligible under typical prominence conditions).

Photospheric and chromospheric line radiation fields incident at the prominence at a given height determine (i) the velocity-dependent radiative rates for all optically-thin lines, and (ii) the velocity-dependent surface boundary conditions for all line transitions treated explicitely (i. e. Lyman lines and $H\alpha$). Both these quantities have been precomputed for a given grid of velocities using the method described by Heinzel (1983). The incident radiation fields used here are identical to those described in Heinzel et al. (1986) and also the continua are treated in a similar way.

In this paper we use the complete frequency redistribution for all lines, but we cannot rule out possible effects of quasi-coherent scattering in $L\alpha$ and $L\beta$ line wings on the velocity-dependent level populations (for higher velocities, most of the incident $L\alpha$ and $L\beta$ radiation is absorbed in the wings).

NUMERICAL RESULTS AND DISCUSSION

From the velocity-dependent level populations we computed the emergent integrated intensities for all lines of interest and for radial velocities in the range of 0 - 240 km/sec. To demonstrate the effect of the prominence motion on the hydrogen-line emission, we define here the relative intensity or brightness $W = E(v)/E(0)$, where E is the velocity-dependent integrated intensity. For the sake of illustration, we have selected one representative isothermal-isobaric model with parameters H=50000 km, $M=1.2\times10^{-5}$ g/cm^2, T=6500K, p=0.1 dyn/cm^2, v_t=0 km/sec (the geometrical thickness amounts about 650 km).

The resulting electron density n_e generally depends on the velocity, but for velocities up to about 200 km/sec this dependence is very weak and n_e can be regarded as nearly constant - this fact allows us to estimate the importance of various MHD-processes leading to density variations.

The behaviour of W for our schematic model is displayed in Fig. 1 for Lyman and Balmer lines.

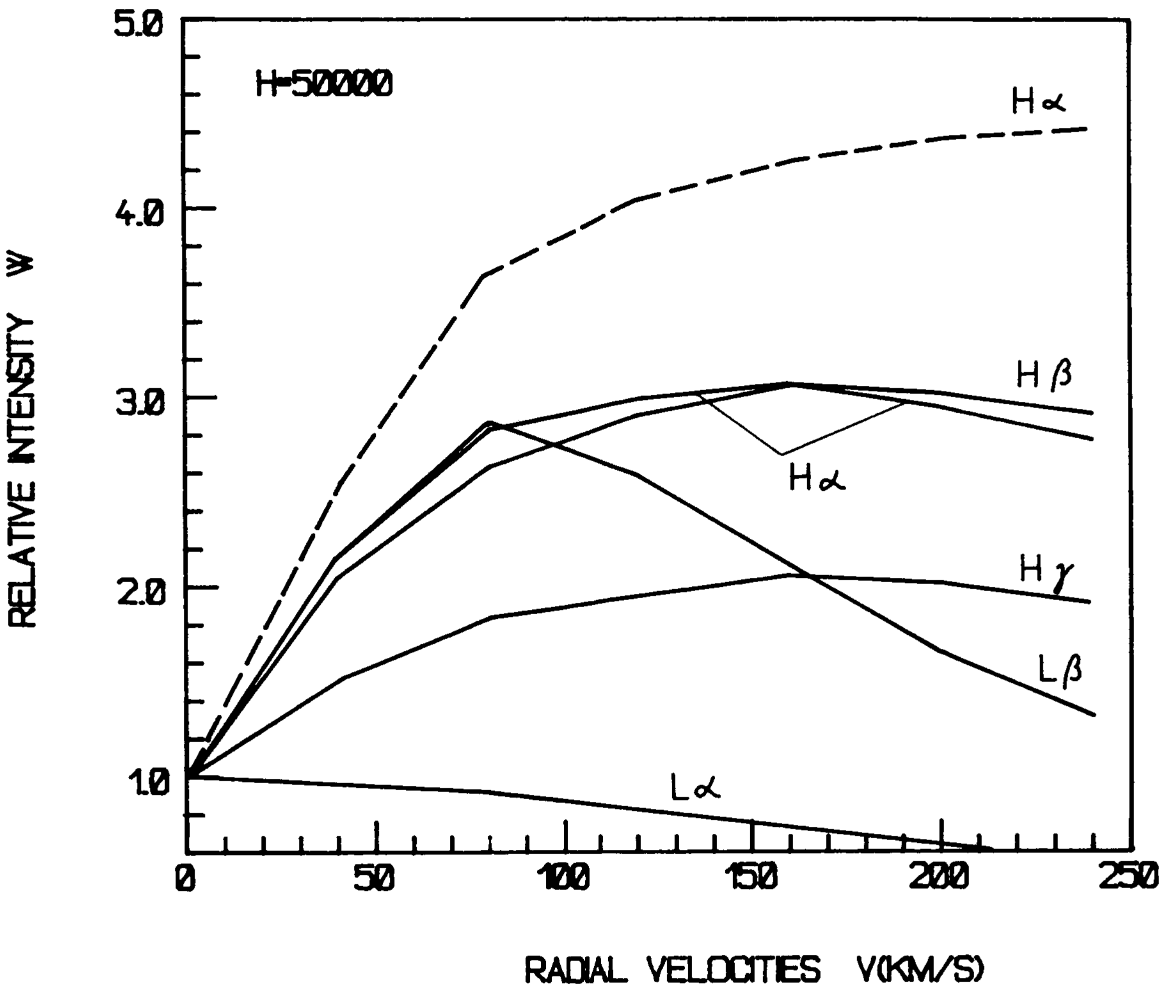

Figure 1

Brightness variations for Lyman and Balmer lines as computed for the model described in the text. Full lines correspond to multilevel non-LTE solution, dashed line corresponds to a two-level model atom without collisions.

Due to a decrease of the second-level population for higher velocities, the $L\alpha$ brightness decreases as demonstrated in Fig. 1 - this decrease represents typical DDE. A more complicated situation occurs for third level, the population of which depends on three factors: DDE in $L\alpha$, a similar effect in $L\beta$ and an important DBE in $H\alpha$ line. The rate of radiative excitation in these lines is roughly proportional to velocity-dependent incident line radiation so that the third-level population inside the prominence body remarkably increases for velocities up to about 160 km/sec (DBE in $H\alpha$ is dominant), and then decreases due to the action of DDE in $L\alpha$ and $L\beta$ itself. Since the third level of the hydrogen atom represents a common upper state for both $L\beta$ and $H\alpha$ lines, the behaviour of the brightness variations in these two lines is similar except for higher velocities, where the optically-thin $H\alpha$ line still exhibits DBE while the surface emission of $L\beta$ is strongly affected by DDE in $L\beta$ itself (see Fig. 1). DBE in $H\alpha$ takes place for velocities up to about 160 km/sec which is in qualitative agreement with the results of Hyder and Lites (1970). A similar behaviour was also found for the $H\beta$ line, while $H\gamma$ exhibits a less pronounced DBE, reaching only a factor of two. Finally, in Fig. 1 we compare our "exact" $H\alpha$ brightness variations with those following from a two-level-atom approximation without collisions (see Rompolt, 1980 a, b). The significant difference between these two curves is the consequence of the multilevel interlocking (including the effect of continua) and the appropriate DDE in $L\alpha$ and $L\beta$ which are not accounted for by the two-level-atom model.

To obtain a more complete picture of the various interdependences, we have also computed some examples using other values of T, v_t and p. An increase of T or v_t generally leads to a prominence brightening, namely for lower velocities. For high velocities, the changes in T or v_t do not affect DBE significantly. Gas pressure p determines the plasma density and, consequently, also the electron density which controls the rate of collisional transitions. As could be expected, for higher n_e we arrived at much less pronounced DBE in Balmer lines since the source function becomes collisionally-dominated. For n_e of the order 10^{13} we observe practically no velocity effects on the line source functions (the model discussed above led to $n_e = 2.43 \times 10^{10}$ cm^{-3}).

Our non-LTE modelling of a moving prominence can equally be applied to other coronal structures like limb flares, cool coronal loops, various types of prominence ejecta and transient $H\alpha$ - phenomena. If the hydrostatic equilibrium used here is replaced by more realistic MHD-equilibria, the present approach can serve as a basis for further development of adequate spectral diagnostics of the prominence plasma and deeper understanding of the relevant radiation-hydrodynamical processes.

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